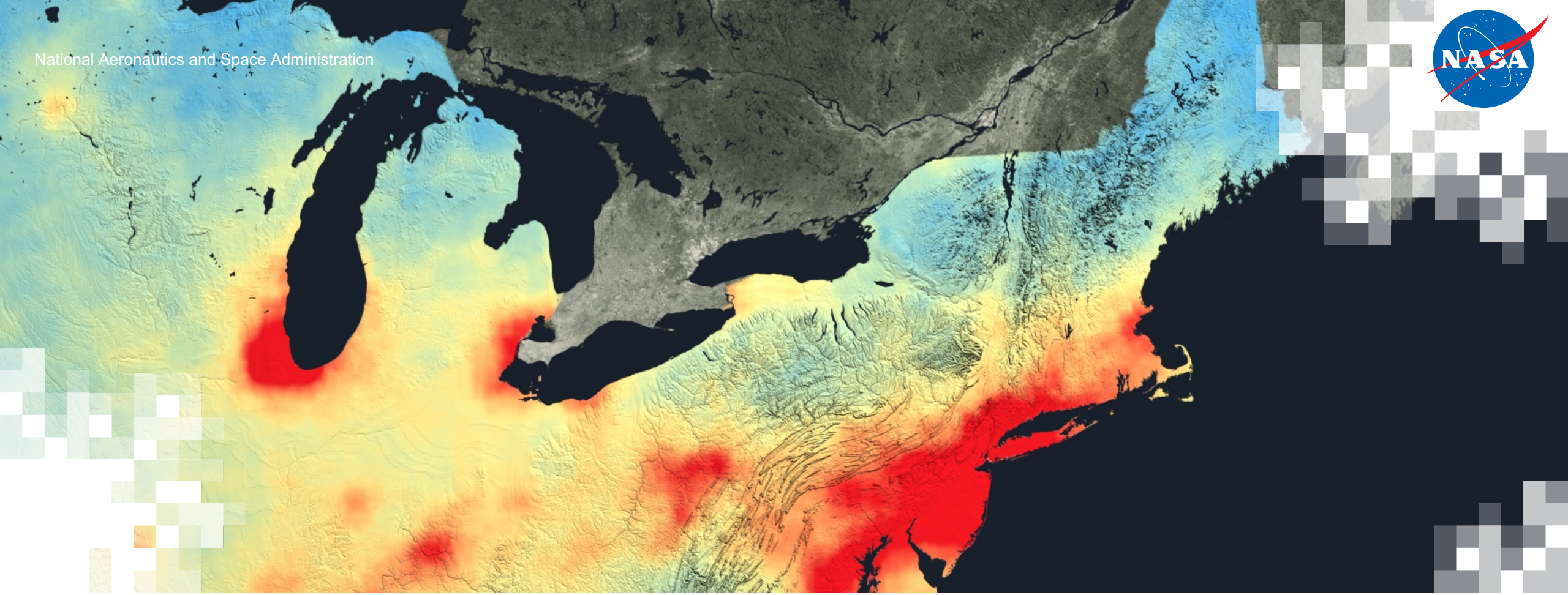


Fundamentals of Satellite Remote Sensing

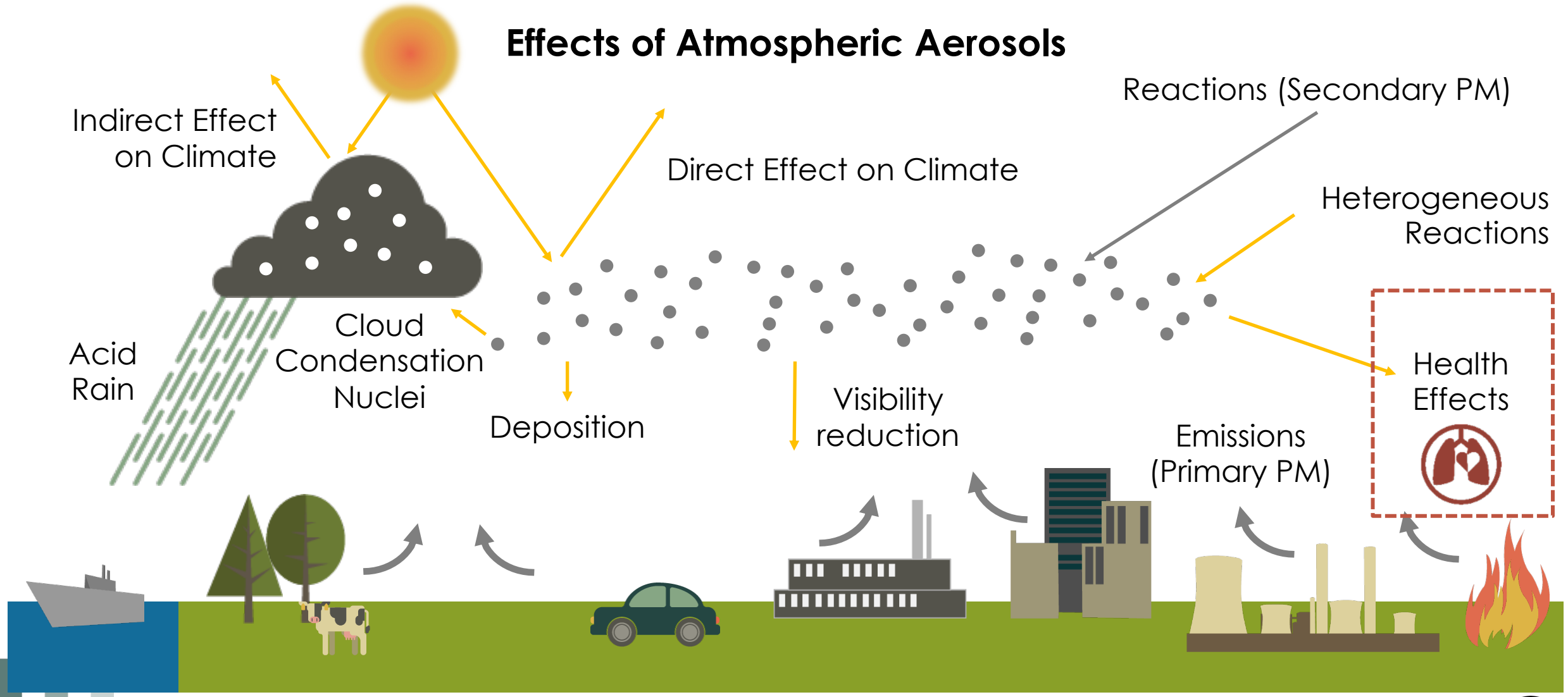
Pawan Gupta, Melanie Follette-Cook, Sarah Strode, Carl Malings

NASA Air Quality Remote Sensing Training, US EPA, Raleigh, NC, March 21-23, 2023

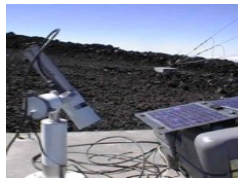
Air Pollution

- Particles (Particulate, Aerosols)
- Gases

Motivation: Tiny, but Potent



Air Pollution Monitoring

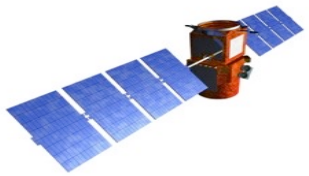



Ground Measurements



Air & Space Observations

Models



NASA EARTH FLEET

OPERATING & FUTURE THROUGH 2023

SWOT (CNES) 2021
LANDSAT-9 (USGS) 2021
SENTINEL-6 B (ESA, EUMETSAT, NOAA) 2025
TROPICS (6) 2020
GEOCARB 2022
NISAR (ISRO) 2020
MAIA 2022
TSIS-2 2023
TEMPO 2022
PREFIRE (2) 2022
PACE (NSO) 2024
GLIMR ~2026
SENTINEL-6 Michael Freilich (ESA, EUMETSAT, NOAA) 2021
ICESAT-2 2021
GRACE-FO (2) (GFZ) 2023
CYGNSS (8) 2023
NISTAR, EPIC (DSCOVR/NOAA) 2023
CLOUDSAT (CSA) 2021
TERRA (METI, CSA) 2023
AQUA (JAXA, AEB) 2023
AURA (NSO, FMI, UKSA) 2023
CALIPSO (CNES) 2021
GPM (JAXA) 2023
LANDSAT 7 (USGS) ~2022
LANDSAT 8 (USGS) >2022
OCO-2 >2022
SMAP 2023
SUOMI NPP (NOAA) >2022

ISS INSTRUMENTS

EMIT 2021
CLARREO-PF 2023
GEDI 2020
OCO-3 2022
TSIS-1 2023
ECOSTRESS 2021
LIS 2023
SAGE III 2023

JPSS-2, 3 & 4 INSTRUMENTS

OMPS-Limb 2022
LIBERA 2027

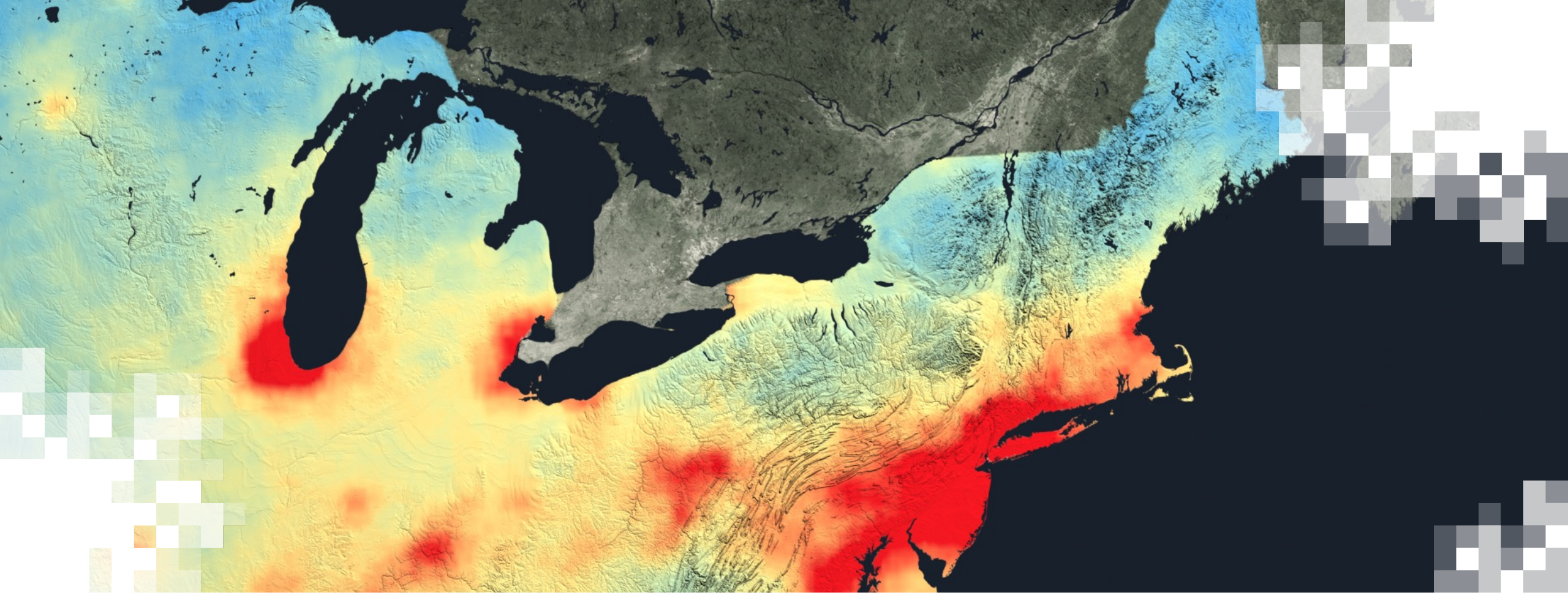
6.21.21

INVEST/CUBESATS

CSIM-FD 2023
HARP 2022
CIRiS 2022
CTIM 2022
HyTI* 2022
SNoOPI* 2022
NACHOS* 2022
NACHOS2* 2022

** Launch date TBD*

(PRE) FORMULATION
IMPLEMENTATON
PRIMARY OPS
EXTENDED OPS



Remote Sensing

What is remote sensing?

Collecting information about an object without being in direct physical contact with it

What is remote sensing?

Collecting information about an object without being in direct physical contact with it

Remote Sensing: Platforms




Images: Natural Resources Canada

- The platform depends on the end application.
- What information do you want?
- How much detail do you need?
- What type of detail?
- How frequently do you need this data?

Remote Sensing of Our Planet

36,000 km

500 km

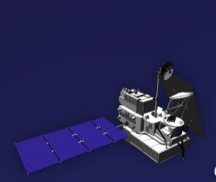
400 km

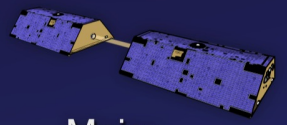
30 km

10 km

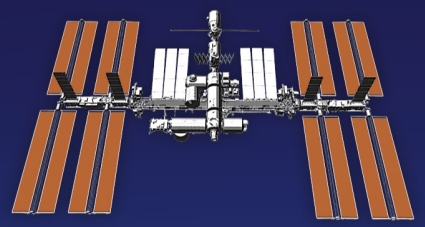
1 km

Near Surface



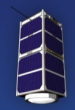


Major Satellite Missions



Sensors aboard the ISS

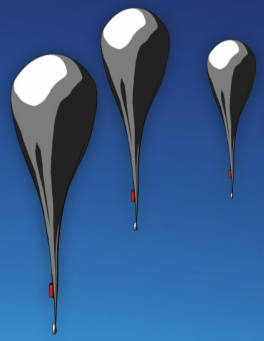
Geosynchronous Meteorological Satellites



HD Video

Cubesats

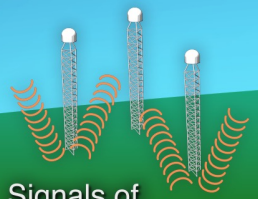
Airborne Instruments



Stratospheric Balloons

UAVs

Tethered Balloon



Signals of Opportunity

Doppler Radar

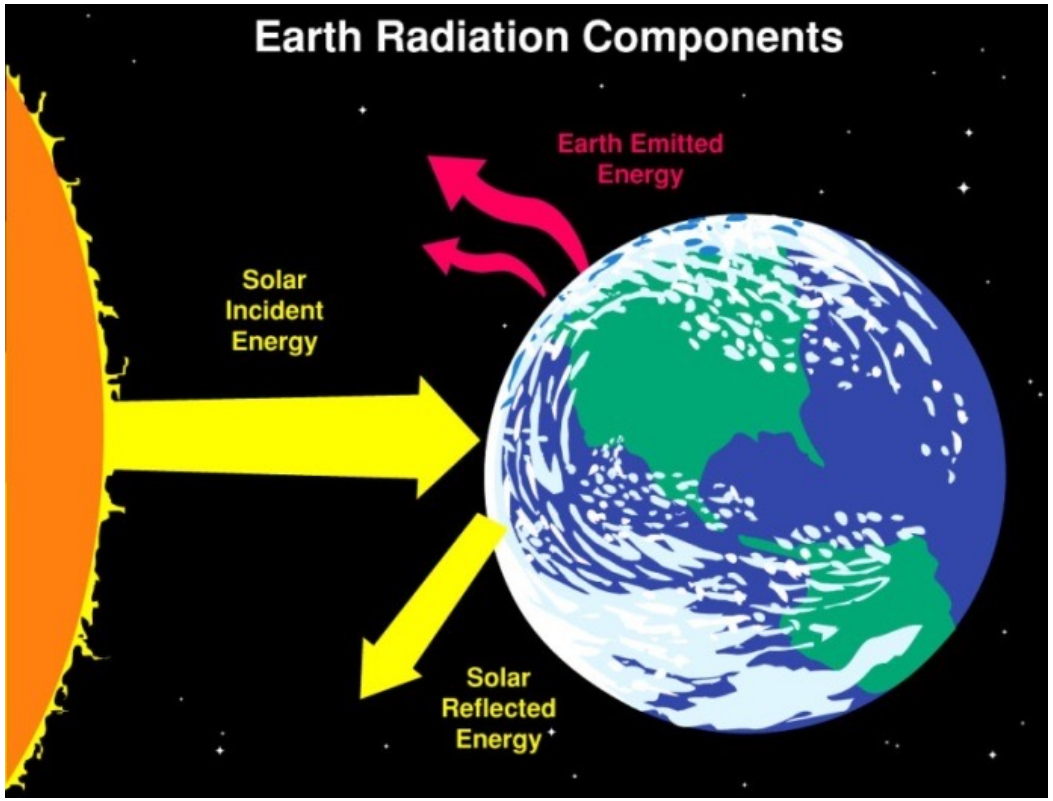
Smart Phones & Citizen Science

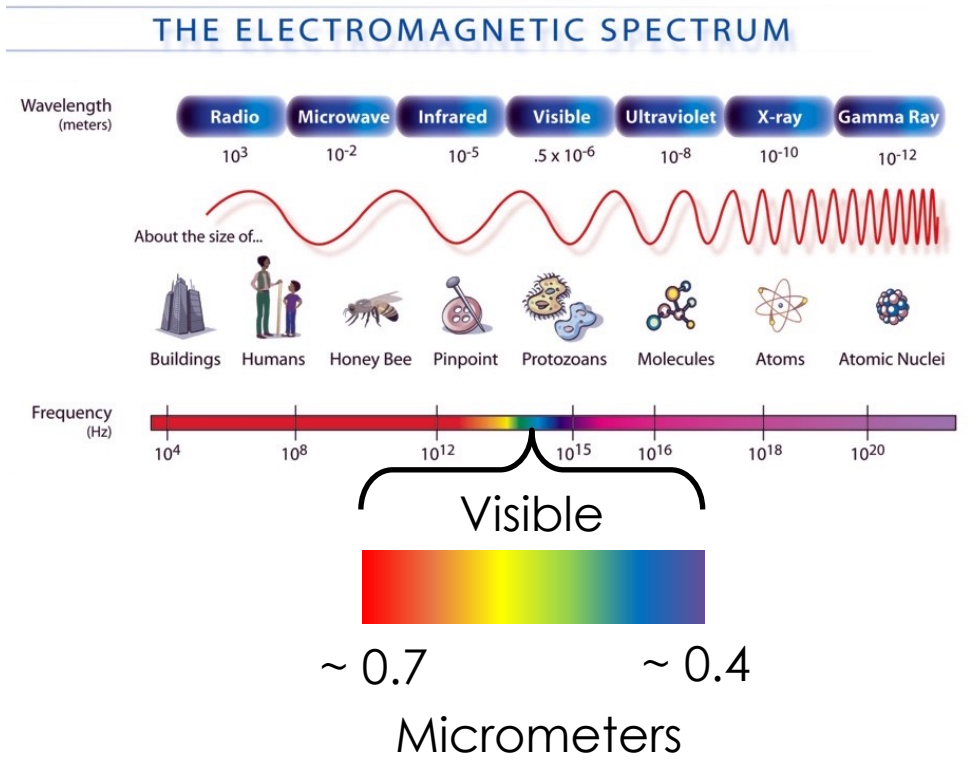
Cell Signals

Mobile Rovers

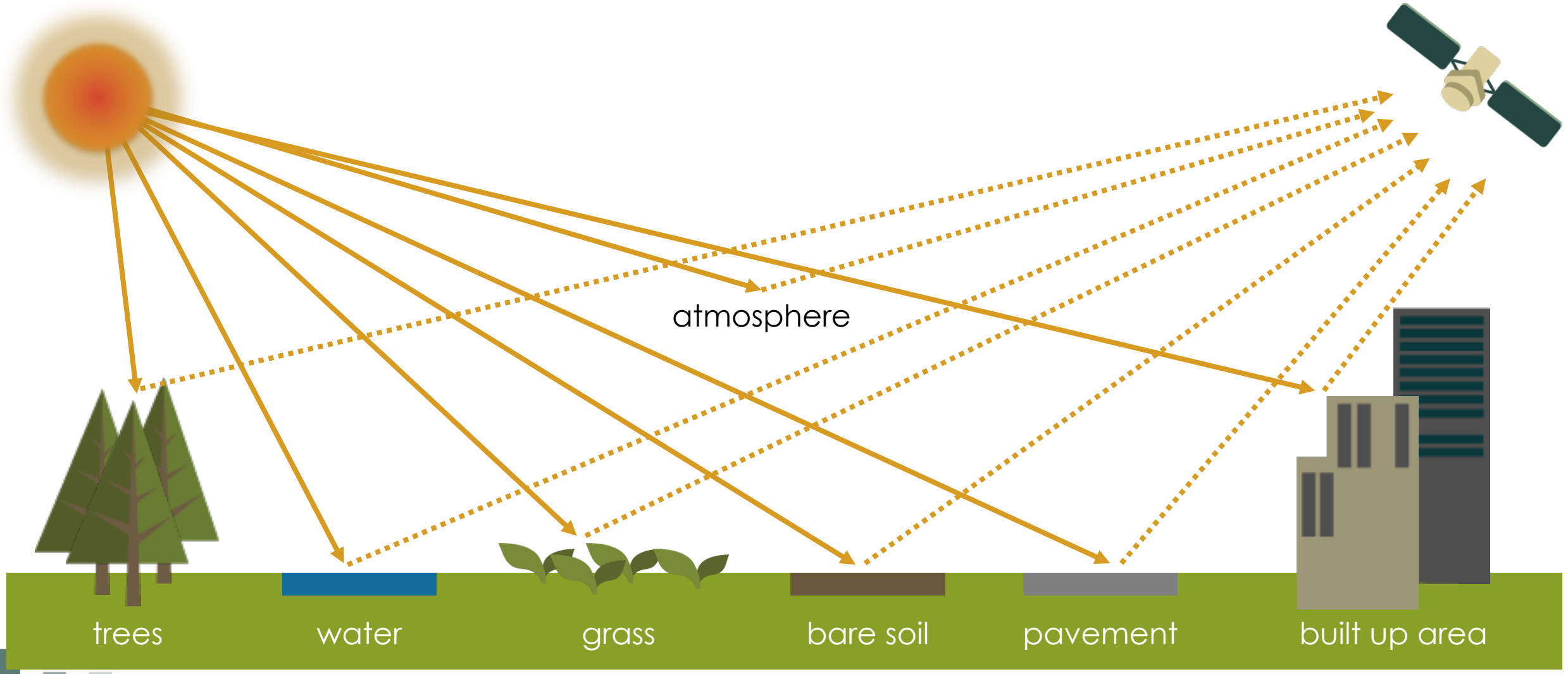
Electromagnetic Radiation

- Earth-Ocean-Land-Atmosphere System
  - Reflects solar radiation back into space
  - Emits infrared and microwave radiation into space



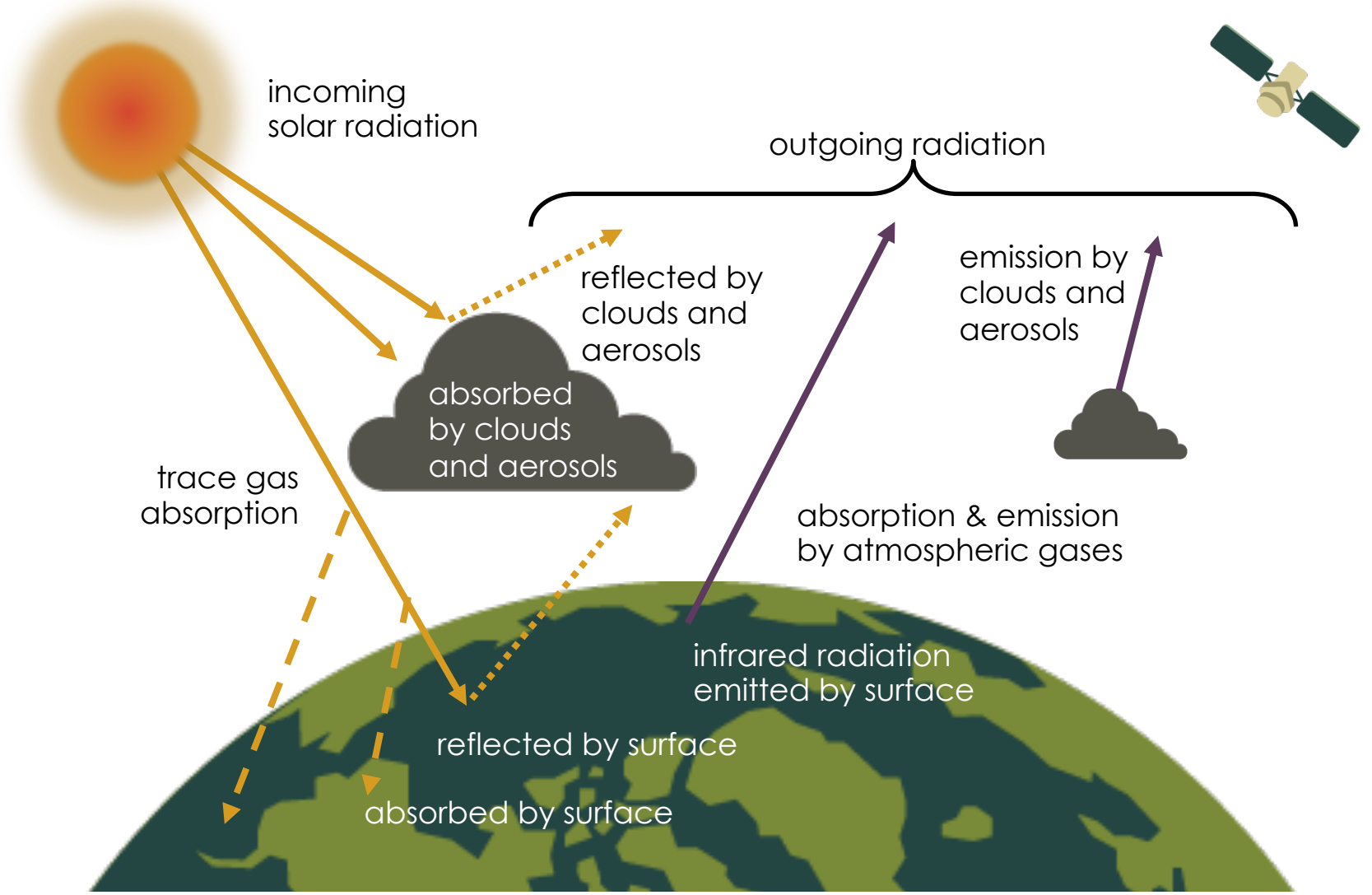


What do satellites measure?

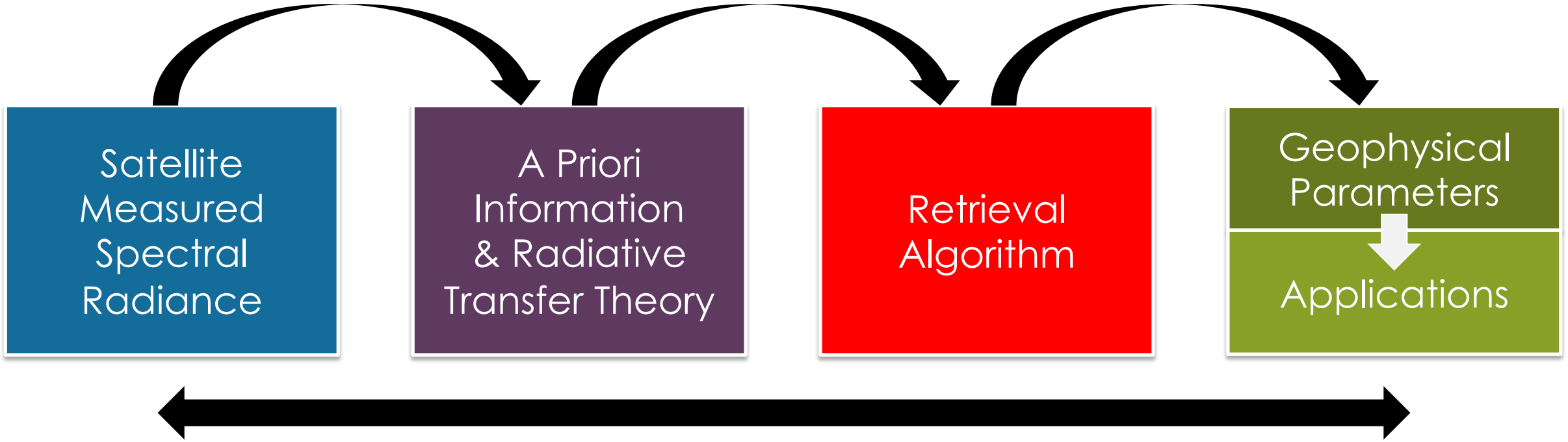


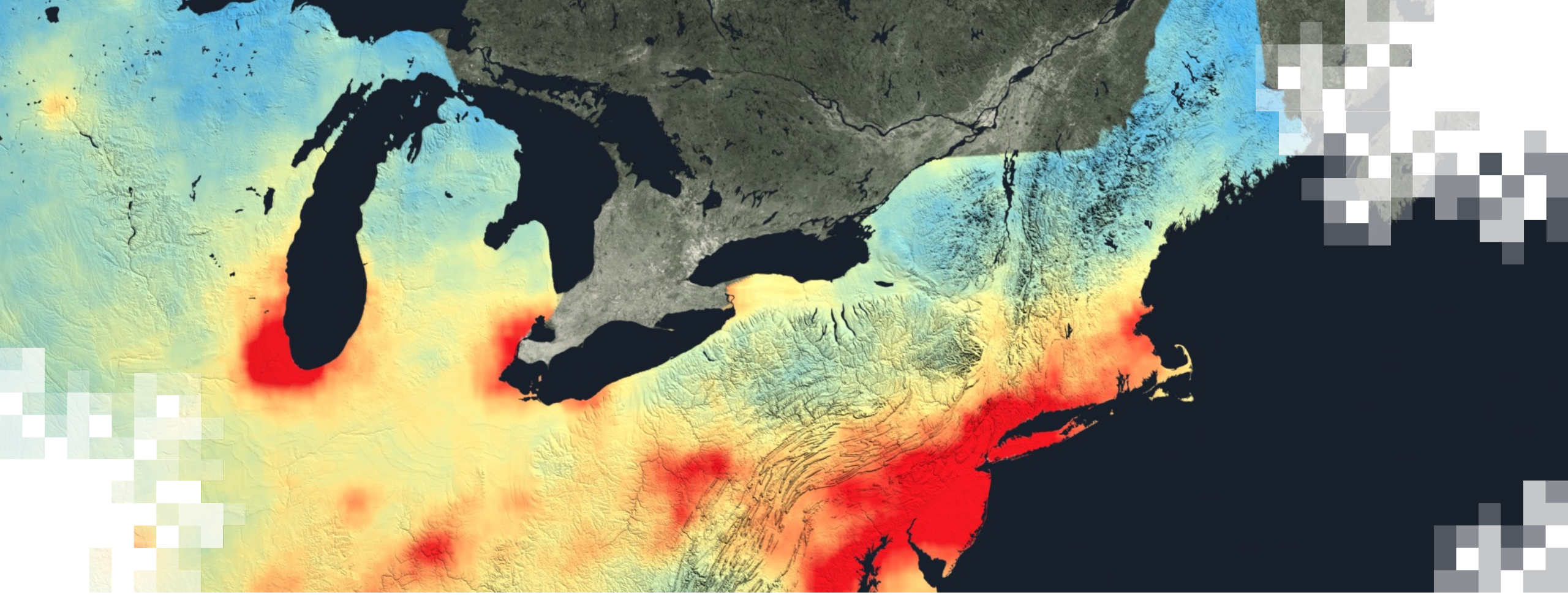
Measuring Properties of the Earth-Atmosphere System from Space

- The intensity of reflected and emitted radiation to space is influenced by the surface and atmospheric conditions.
- Satellite measurements contain information about the surface and atmospheric conditions.



The Remote Sensing Process





Satellites, Sensors, and Orbits

Satellites vs. Sensors

Earth observing satellite remote sensing instruments are named according to:

1. The satellite (platform)
2. The instrument (sensor)

Naming Convention

- Before Launch: GOES-R & GOES-S
- After Launch: GOES-16 & GOES-17
- Operational in Final Orbit/Position: GOES-East & GOES-West

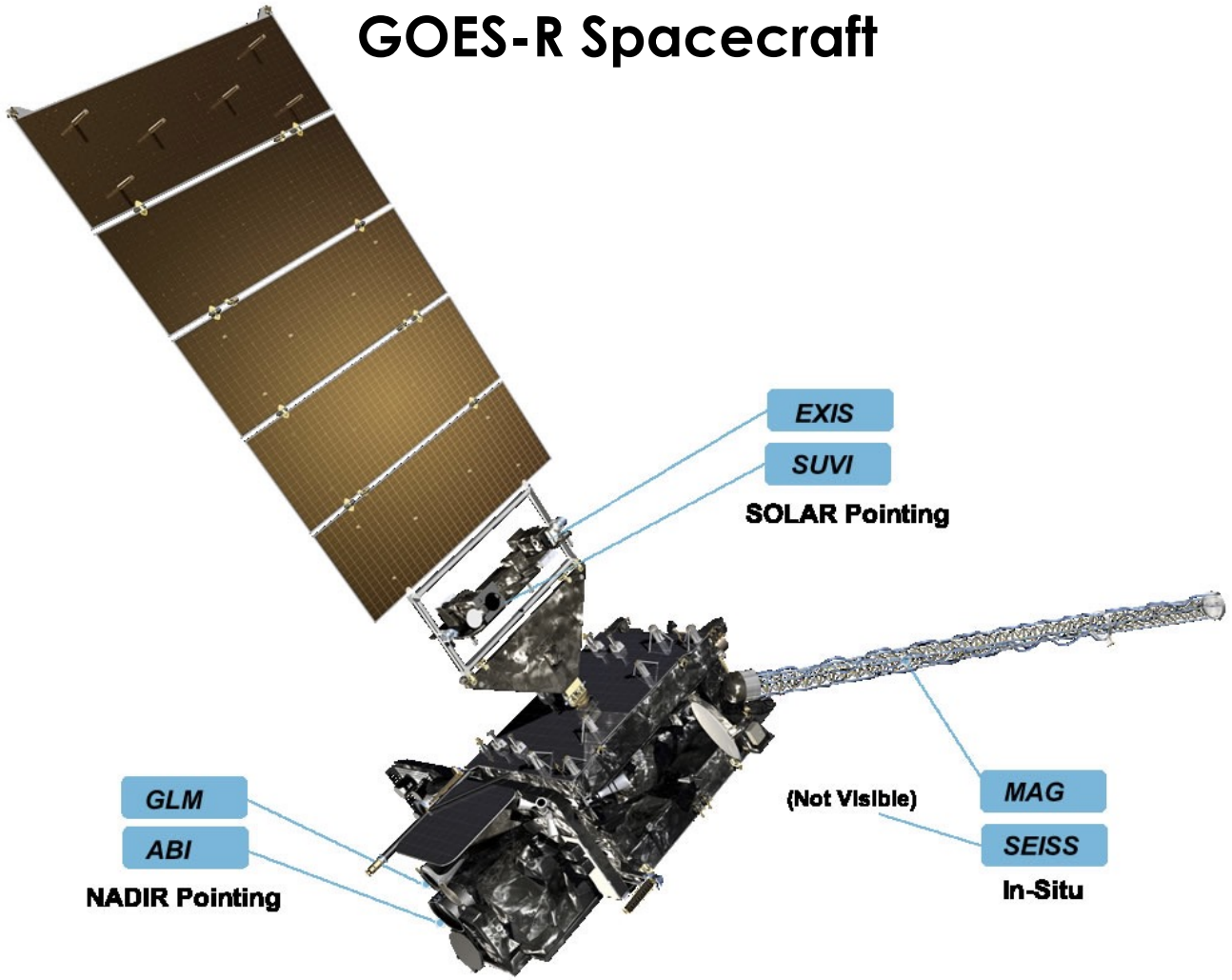
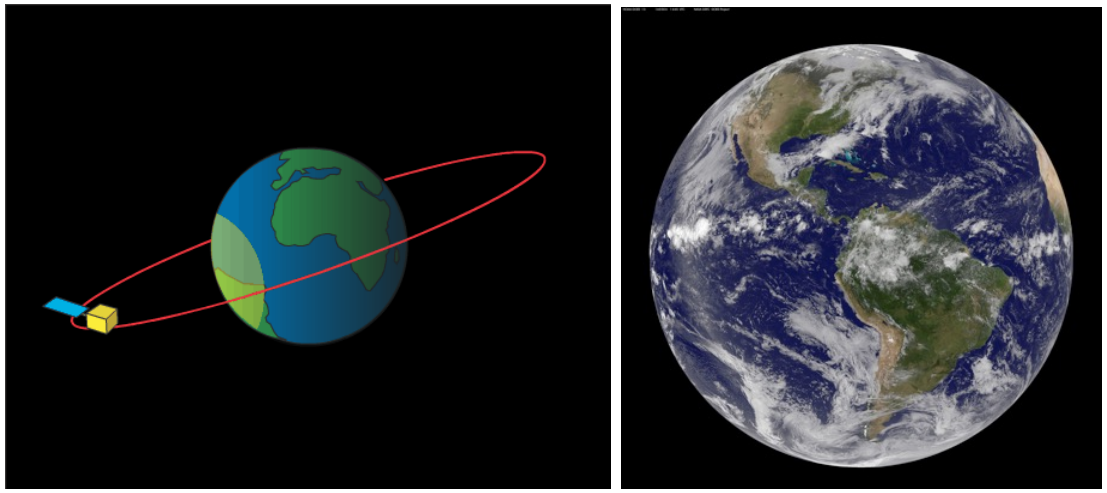


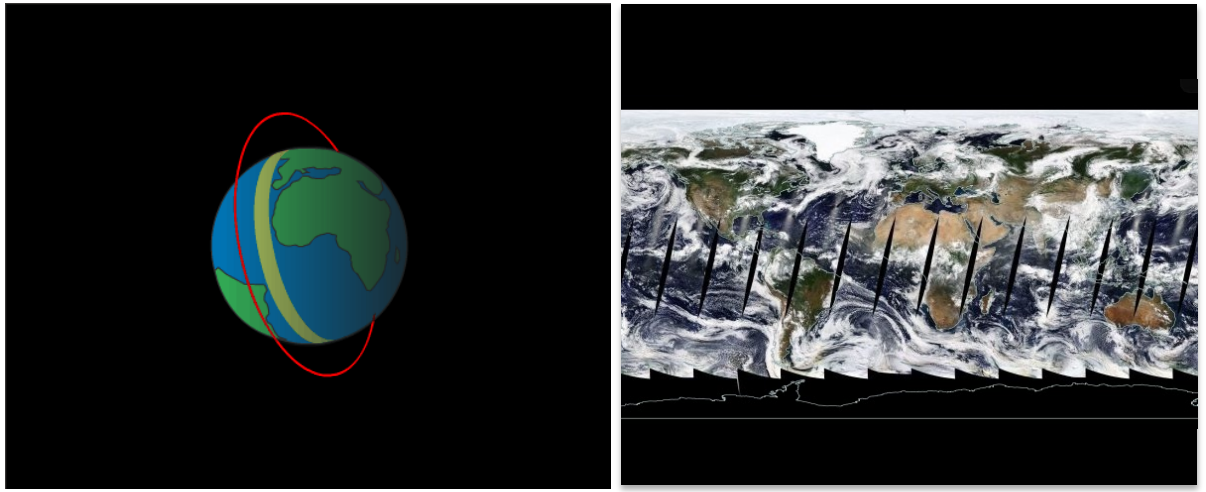
Image Credit: NASA/NOAA

Common Orbit Types



Geostationary Orbit

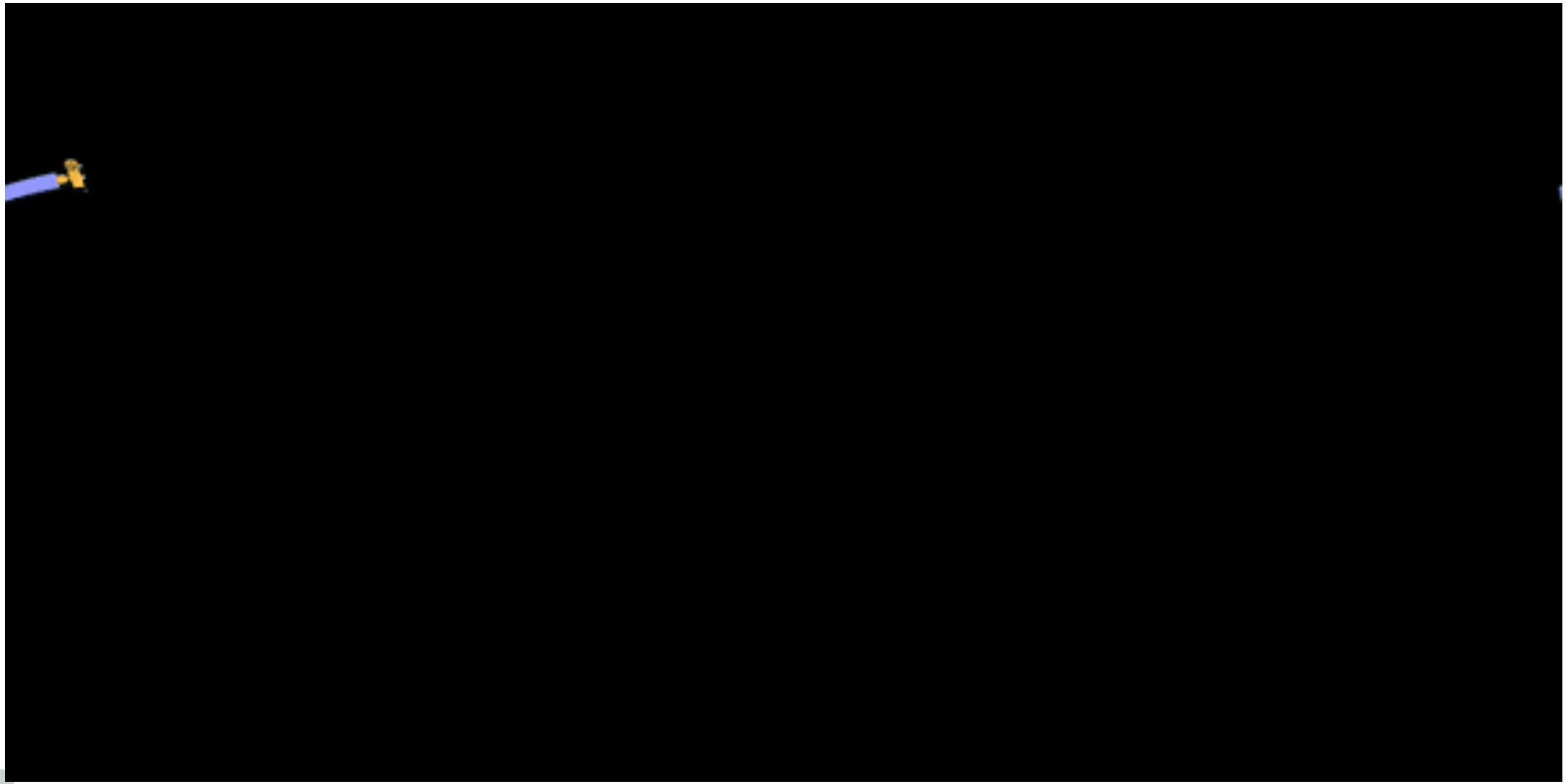
- Has the same rotational period as Earth
- Appears 'fixed' above Earth
- Orbits ~36,000 km above the equator
- **TEMPO - 35 786 km, 91° West, above the equator**



Polar Orbit

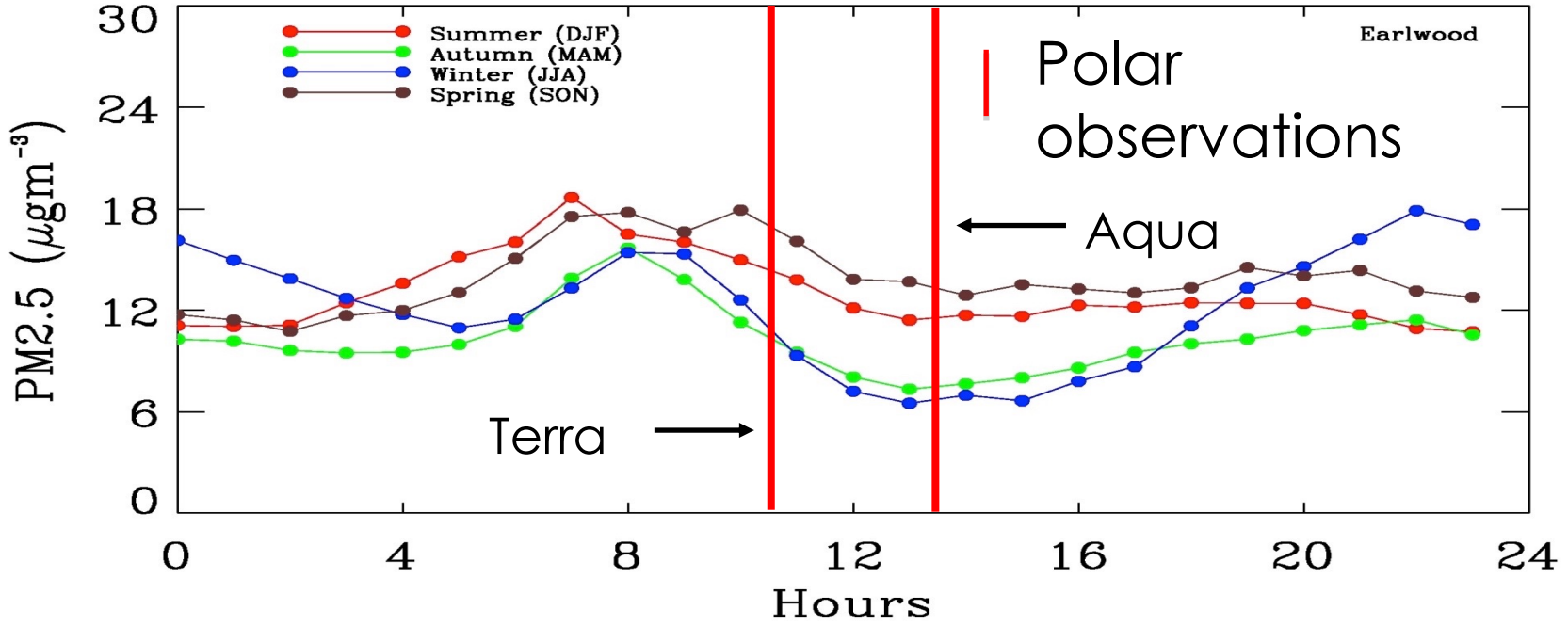
- Fixed, circular orbit above Earth
- Sun synchronous orbit ~600-1,000 km above Earth with orbital passes are at about the same **local solar time** each day
- **NOAA-20, 833 km, 101 min (orbital period)**

Aqua Satellite Orbiting the Earth



Observation Frequency

Polar Orbiting Satellites: 1-3 observations per day, per sensor

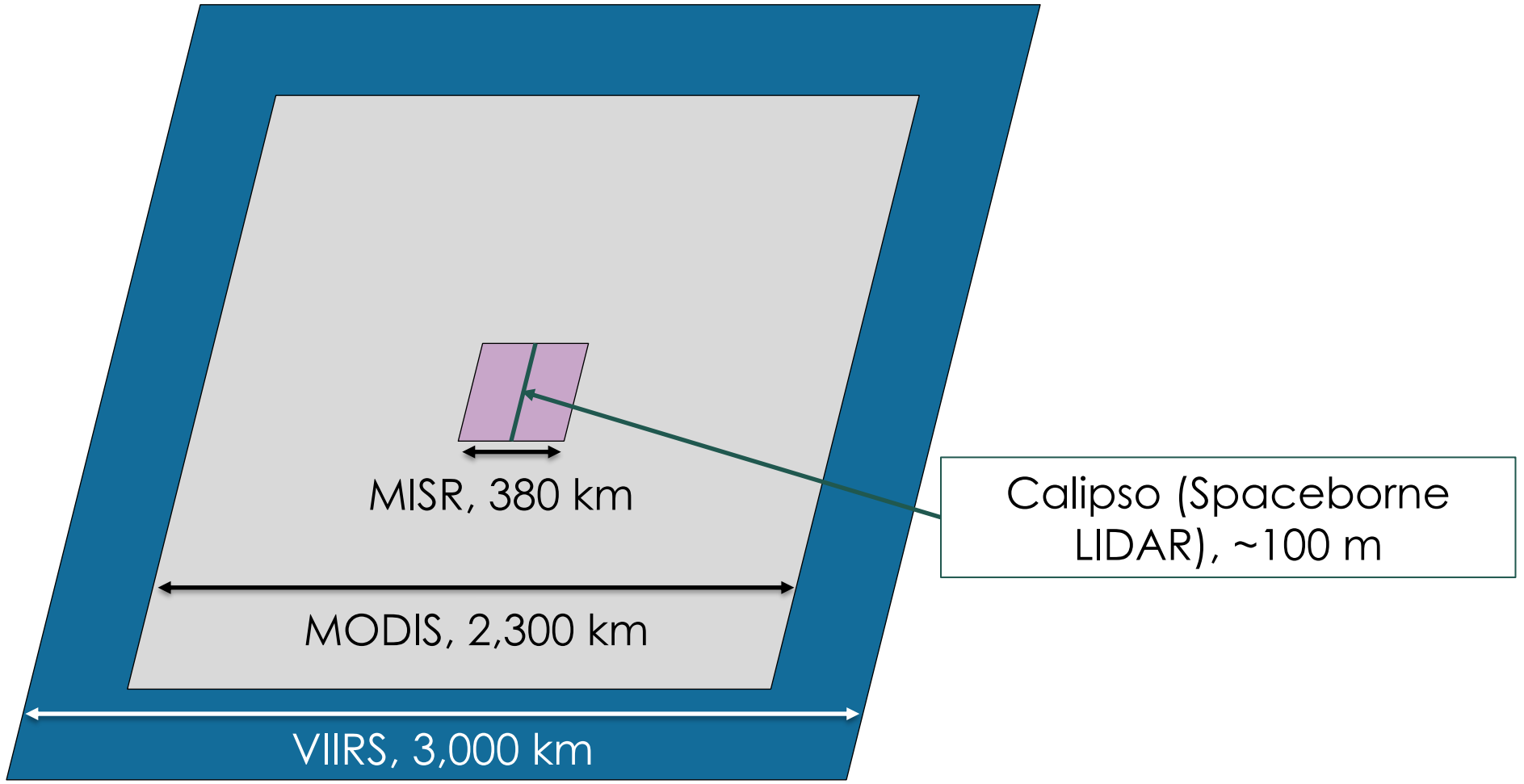


Geostationary Satellites: Every 30 sec. to 10 min.

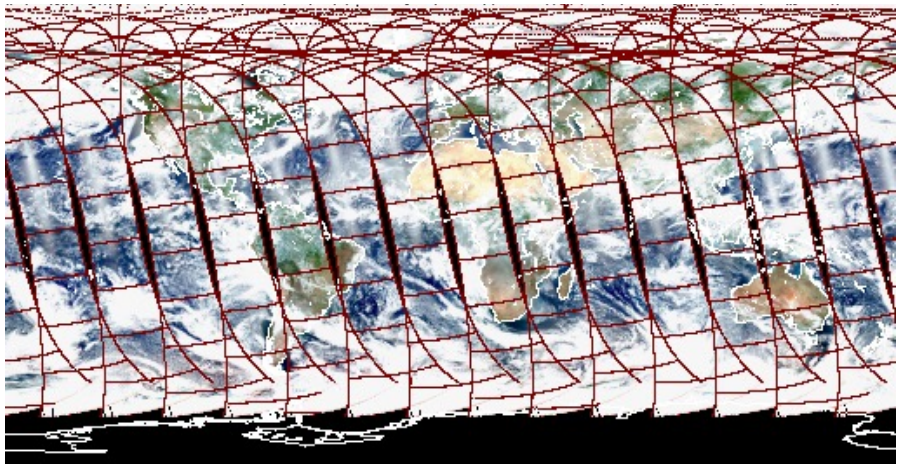
Future Geo Satellites: TEMPO, GEMS, Sentinel-4

Source: P. Gupta

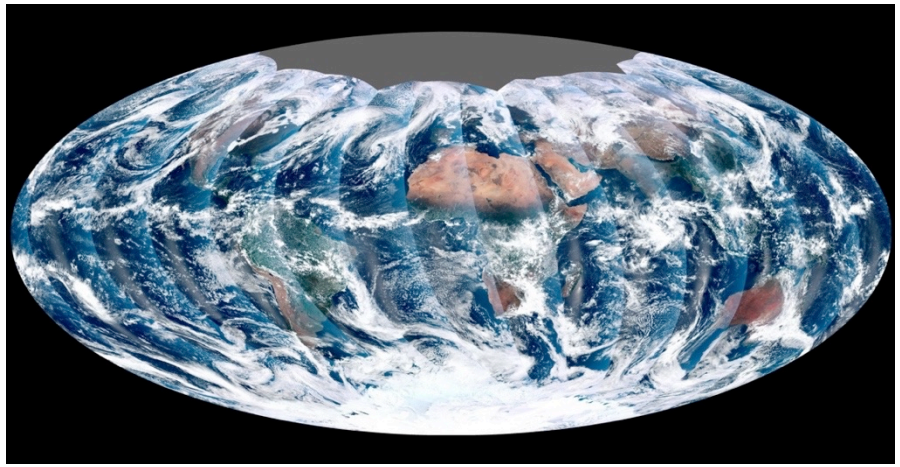
Satellite Coverage – Swath Width



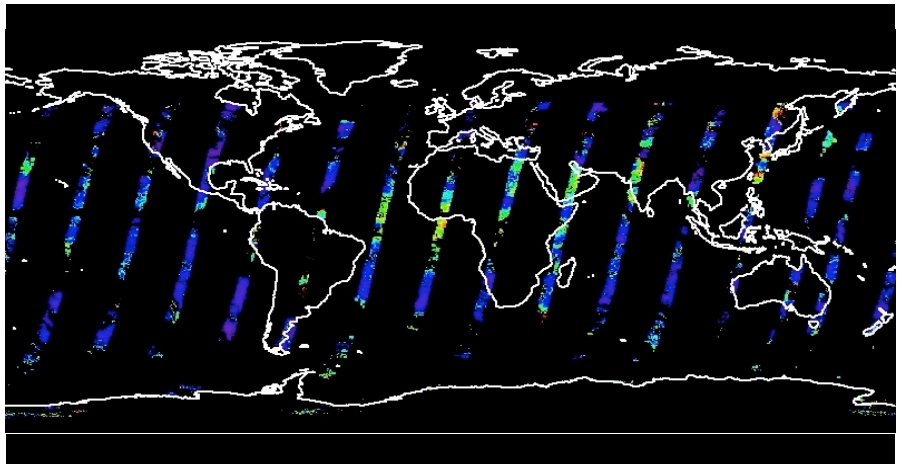
Satellite Coverage - LEO



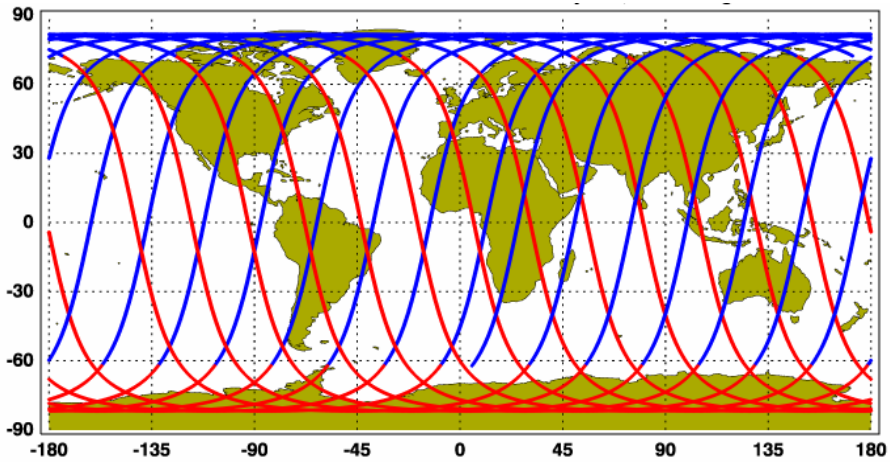
MODIS



VIIRS

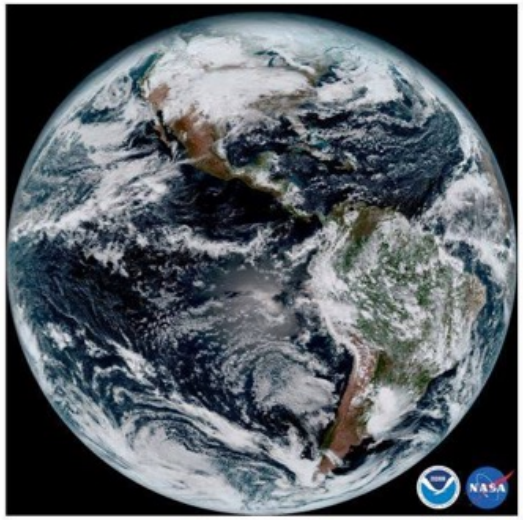


MISR

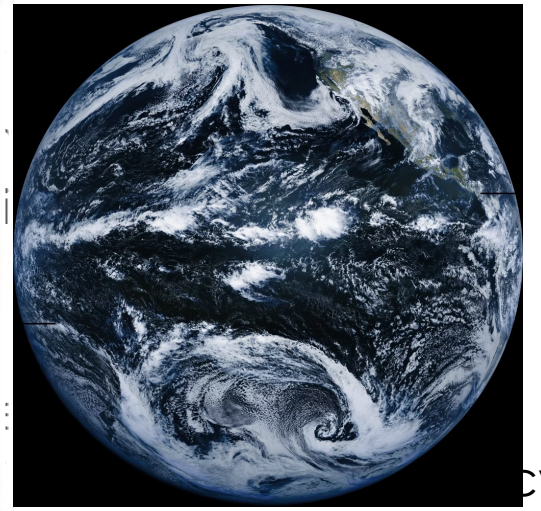


CALIPSO

Satellite Coverage - GEO



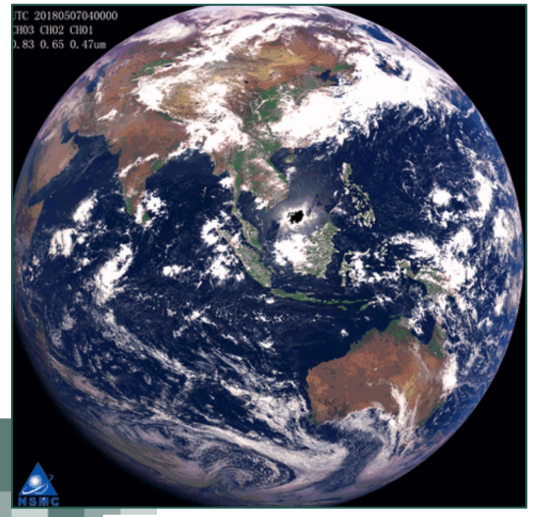
GOES-R



GOES-S/T

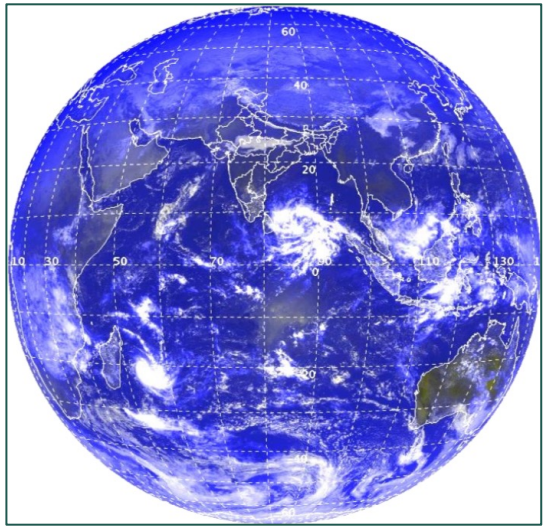
Himawari -8/9

AMI-GK-2A



Fengyun-4

MST – (FCI)

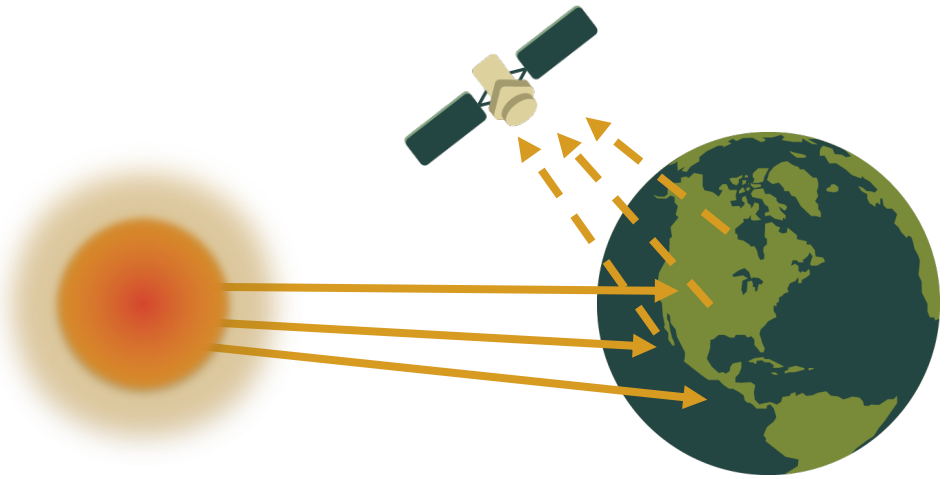


INSAT – (GISAT)

Geostationary satellites provide high frequency (sec-to-min) measurements over a region.

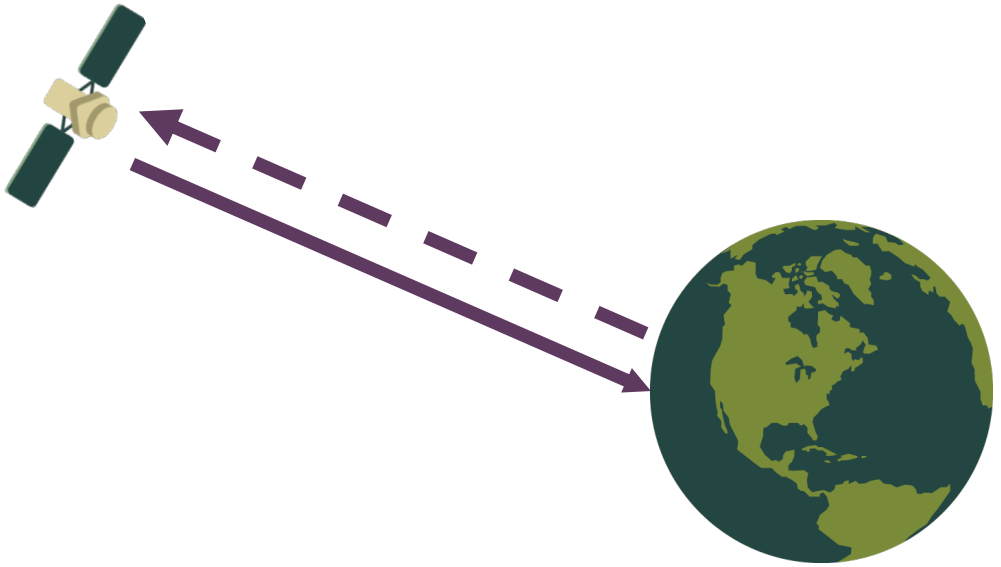
Active & Passive Sensors

Passive Sensors



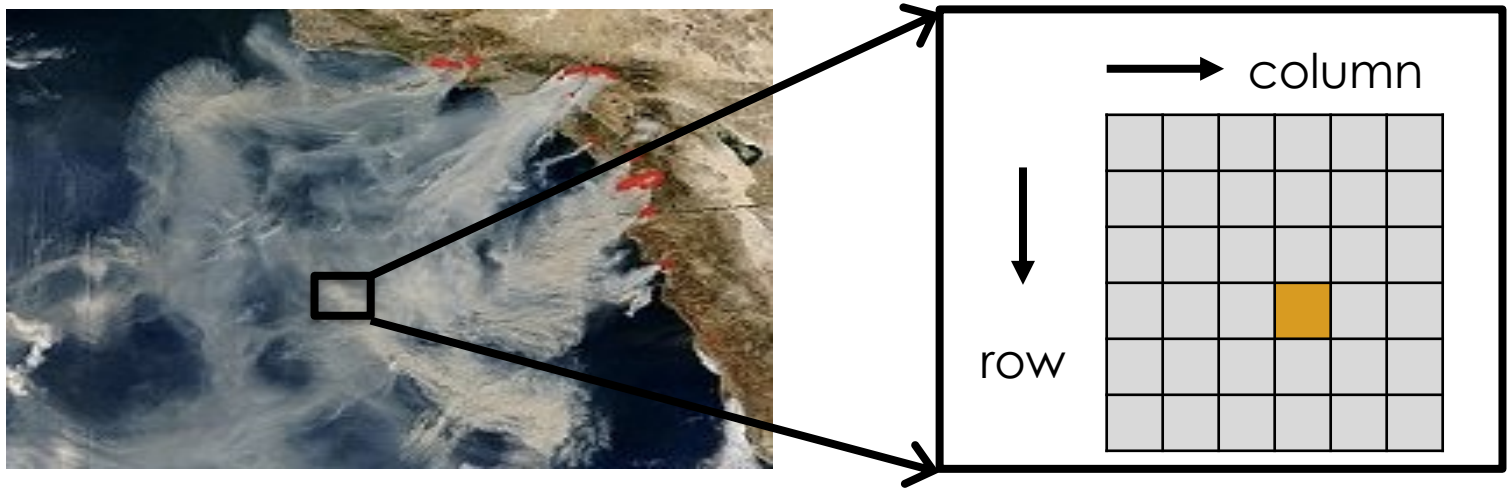
- Detect only what is emitted from the landscape, or reflected from another source (e.g., light reflected from the sun)
- Examples: (**MODIS, MISR, OMI, VIIRS**)

Active Sensors



- Instruments emit their own signal and the sensor measures what is reflected back (e.g., sonar and radar).
- Example: **CALIPSO**

Pixel – The Smallest Unit of an Image

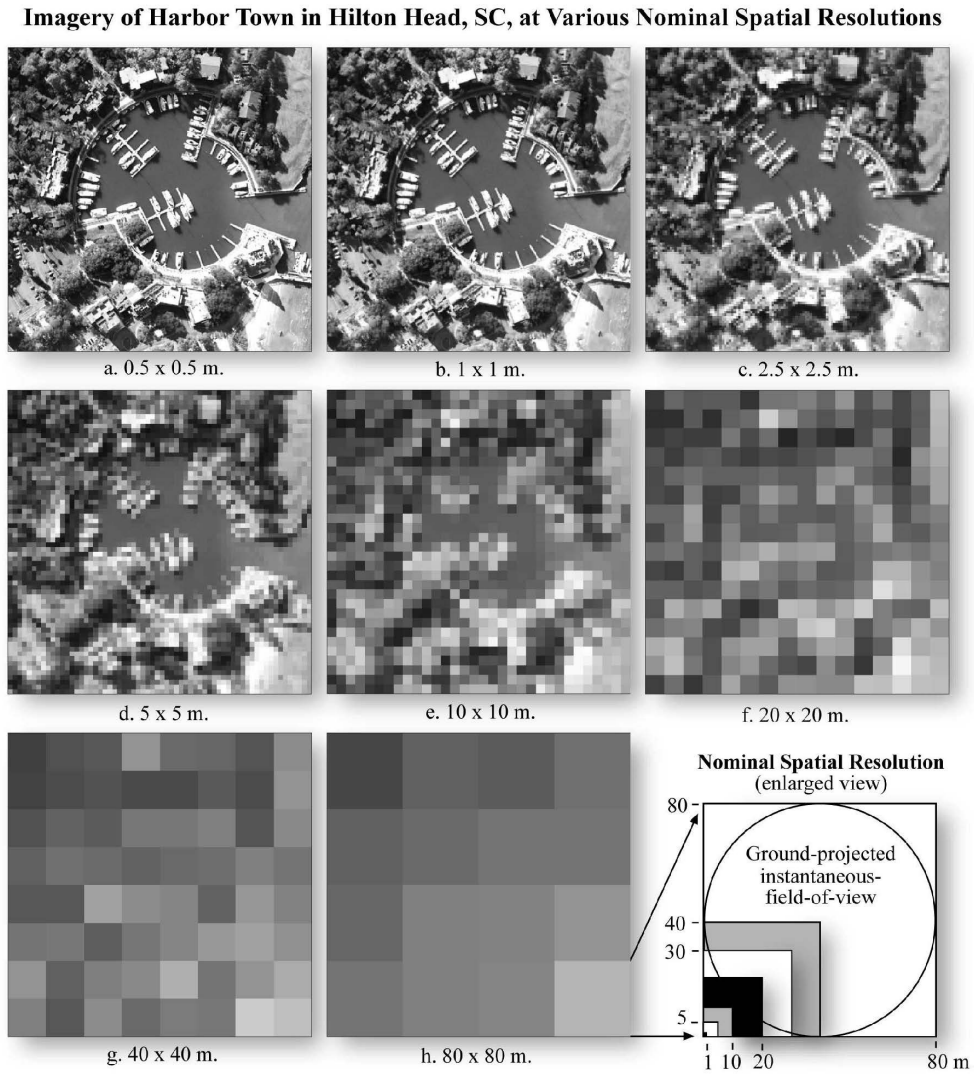


- A digital image is comprised of a two-dimensional array of individual picture elements (called pixels) arranged in columns in rows.
- Each pixel represents an area on the Earth's surface.
- A pixel has an intensity value and a location address in the 2D image.
- Spatial resolution is defined by the size of a pixel.

*Text Source: Center for Remote Imaging, Sensing, and Processing

Why is spatial resolution important?

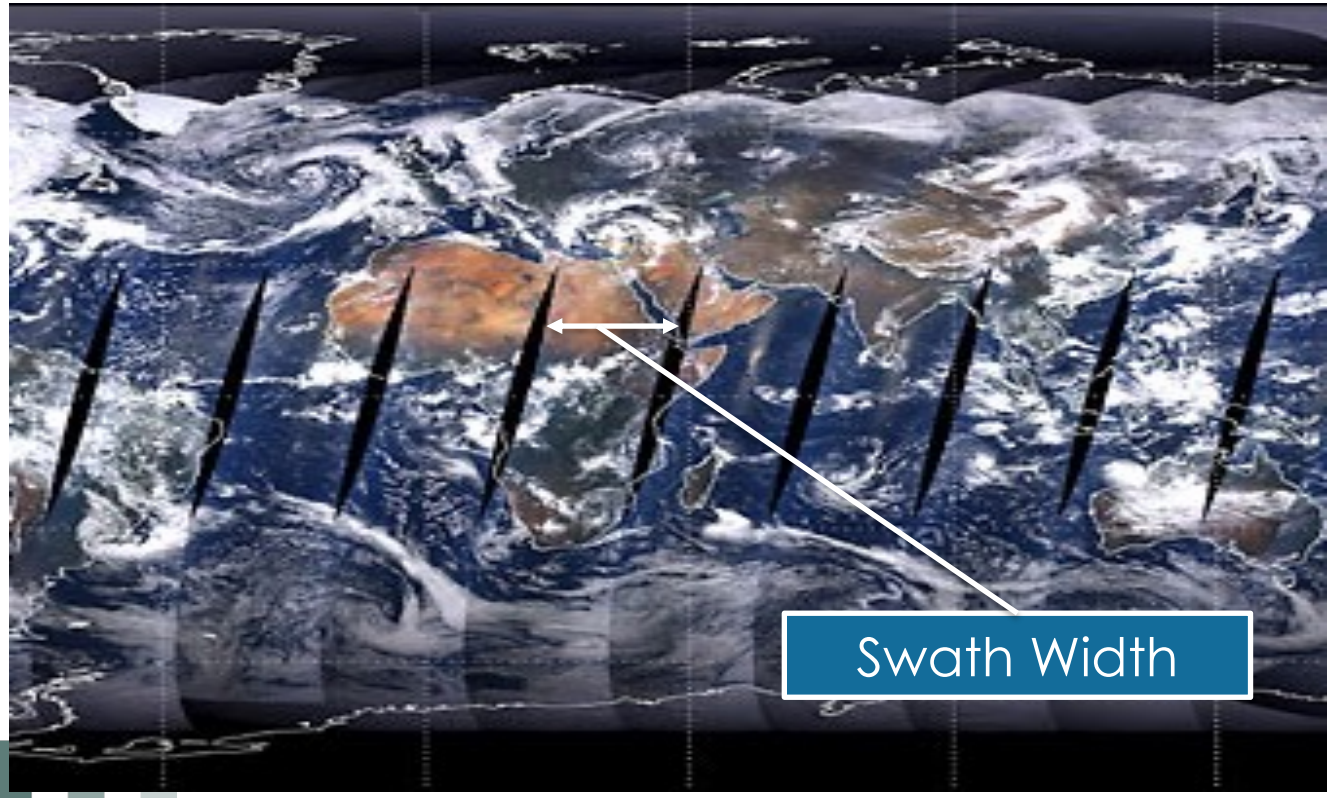
- MODIS
  - 250 m – 1 km
- MISR
  - 275 m – 1.1 km
- OMI
  - 13x24 km
- VIIRS
  - 375 m



Source: Introductory Digital Image Processing, 3rd edition, Jensen, 2004

Temporal Resolution

- How frequently a satellite can provide observation of the same area on the earth
- It mostly depends on swath width of the satellite (the larger the swath – the higher the temporal resolution).



Global coverage in….

- MODIS
  - 1-2 days
- OMI
  - 1 day
- MISR
  - 6-8 days
- VIIRS
  - 1 day
- Geostationary
  - 30 sec – 1 hr

Remote Sensing – Types of Resolution

- **Spatial Resolution**
  - Smallest spatial measurement
- **Temporal Resolution**
  - Frequency of measurement
- **Spectral Resolution**
  - Number of independent channels
- **Radiometric Resolution**
  - Sensitivity of the detectors

Each resolution depends on the satellite orbit configuration and sensor design.
Resolutions are different for different sensors.

Characterizing Satellites and Sensors

- **Orbits**
  - Polar vs. Geostationary
- **Energy Sources**
  - Passive vs. Active
- **Solar and Terrestrial Spectra**
  - Visible, UV, IR, Microwave…
- **Measurement Techniques**
  - Scanning, Non-Scanning, Imagers, Sounders...
- **Resolution (Spatial, Temporal, Spectral, Radiometric)**
  - Low vs. High
- **Applications**
  - Weather, Land Mapping, Atmospheric Physics, Atmospheric Chemistry, Air Quality, Radiation Budget...

Remote Sensing Tradeoff

It is **very difficult** to obtain extremely high spectral, spatial, temporal, **AND** radiometric resolutions, all at the same time.

References and Further Reading

- Natural Resources Canada: http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9309
- Center for Remote Imaging, Sensing, and Processing: http://www.crisp.nus.edu.sg/~research/tutorial/image.htm
- NASA Earth Observatory: http://earthobservatory.nasa.gov/Features/RemoteSensing/remote_06.php
- EOS-Goddard: http://fas.org/irp/imint/docs/rst/Front/tofc.html
- Spectral Resolution: http://web.pdx.edu/~jduh/courses/Archive/geog481w07/Students/Cody_SpectralResolution.pdf